The function of the secondary lining in the New Austrian Tunnelling Method

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ABSTRACT: The decision to build the Secondary Lining in Route Tunnels which are perforated using the New Austrian Tunnelling Method does not generally depend on reasons of structural strength. The paper discusses the implications of the issue as well as the pros and cons of the current alternative courses of action.

1 INTRODUCTION

The New Austrian Tunnelling Method (NATM) is based on the equilibrium reached between the natural soil and the primary lining (Rabcewicz 1964), nevertheless, a secondary lining (SL) is usually erected that, may be, is redundant from a safety viewpoint because the strength is, at least theoretically, completely provided by the primary lining (PL).

The objective of this paper is precisely to analyse if the construction of a SL (generally of poured concrete) implies such benefits that can balance the increase in cost. In the analysis it is important to keep in sight that tunnels are high cost public works that act as alternative ways to other ones which have worse properties (mountain pass, urban tunnels, etc.) so that once in service, the traffic interruption will imply costly disturbances.

2 STRUCTURAL ROLE OF THE SECONDARY LINING

The role played by the S.L. in the NATM has been well understood (see references); the main conclusions are:

- In spite of its economic relevance it is surprising to see the scarcity of papers treating the possibility of avoiding the construction of the S.L.
- There are not many examples of route tunnels without S.L.
- Conceptually and from a strictly strength viewpoint the S.L. is not a part of NATM.
- Muller (1990) collects 22 NATM fundamental principles while Brown (1990) presents 7. The most interesting are: a) The fundamental work is developped by the rock itself, b) The P.L. acts really confining the soil, c) It is necessary to control the derfomation process along time in order to asses the stability both in the short and the long range, d) It is fundamental to guarantee the development and maintenance of a soil ring that can act as thick tube.

That means that the P.L. has to fill the following objectives: a) the shotcrete has to mantein the continuity and adherence during the whole tunnel life, b) the Safety margin has to be relatively high (Rabcewicz recommends a factor af 2) to avoid the degradation of soil properties. c) it is vital to produce the clousure of the rock ring because it will have to carry the main loads.

3 PROS AND CONS OF THE SECONDARY LINING

Some of the most interesting points about the S.L. are the following.

- Higher cost of the secondary lining (S.L.).
- It is possible to classify the cost of the route tunnels according to table I (Constantin 1982) and the total cost by running meter by following table II (Constantin 1990).

- As an example the cost of a two-way tunnel 2000m long would be about 30.10^6 \$ of wich 85% directly related to the tunnel construction; the S.L. is 30 to 35% of that cost so that the cost of the S.L. represents 25,5% to 29,75% of the total tunnel cost.

- The above mentioned cost refer to a decision taken in advance to the construction; the possibility of constructing a S.L. after a time and with the tunnel in full service is not dealt with in this paper.

3.1 *Constructive implications of a* S.L.

If in the initial design a pay line for the Excavation Profile is established, it will be the only basis for the payment. The line depends on the type of soil (or rock) .and is selected in such a way to represents an "actual" mean value of the Excavation Profile.

If, in addition, an Interior Profile (fixed by the establishment of a Model Cross-Section) is selected with a minimum thickness of the S.L. the Contractor will be obliged to build it.

Both conditions demand

a) A realistic definition of the Pay-Line, which is not an easy task neither in the Design nor in the Tendering steps.

b) A very careful construction (specially if blasting is used).

If the construction is not adjusted to the Play-Line the S.L. concrete would greatly exceed the foreseen amounts.

3.2 *Managing, Lighting and Ventilation*

There are several pros in favour of the S.L.: less head losses in the ventilation and more uniformly distributed flow, with less turbulences; possibility of ventilating the more difficult zones with less energy (low comers of the side-walls when using longitudinal ventilation, etc.).

The circulation through a tunnel imposes into the driver a sudden accommodation to the new conditions of the neighbourhoods. When there is a S.L. the conditions are more homogeneous. On the contrary, the lighting has to be studied not only to make visible the way but to avoid the perception of the wall discontinuities (side-wall and vault discontinuities). On its part the lighting will be easier to maintain, to clean and the efficiency will be higher.

If the S.L. is not built it will be necessary, by aesthetic reasons, either concreting the side walls until a certain height or to use precast elements with an important additional cost.

The S.L. supplies also a surface with enough strength to anchor differente elements (signals, luminaries, traffic lights, cable trays, pipes, etc.).

3.3 *Reparations, Monitoring and Safety*

There are several pros to build a S.L.; if while in service, for instance, a need to add some bolts or shotcrete reinforcement is suspected it will be necessary both to have always at hand the Equipment and to interrupt temporarily the tunnel trafic. And that has to be done immediately without any possibility to postpone the decisions.

The S.L. offers a guarantee to avoid the falling of a piece of the P.L. or a block inside the tunnel (due to thermal changes, vibrations, etc) which even when of small size, could induce unforseen drivers reactions.

Also the S.L. could help in front of a possible bolt loosening or if it is decided to do some grouting to consolidate some part of the ground.

Some of the measurements to monitor the tunnel behaviour are more difficult with the tunnel in service. The convergence measurements for instance are practically impossible to get with a regular frequency. In that respect the smoothness of a S.L. could help to detect any anomaly.

The S.L. protects the metallic elements (head bolts, reinforcement, stell sets, etc.) in front of corrosive agents. Last but not least in front of fires the S.L. is a very important defence line both of the resistant structure and of the ground.

The main cons against the S.L. are related to the possibility of having a direct look on the P.L. what could help to detect quickly any anomaly of the resistant structures although it is wise to recognise that the visual inspection is very difficult due to the roughness of the P.L. surface. Also the possibility of enlargering the perforation (for parking, lay-bys for emergencies, etc.) grows complicated due to the demolitions in the S.L.

3.4 *Waterproofing*

The adventage of having a S.L. in order to provide water tightness to the lining is the possibility of using an impervious film between the primary and the secondary lining while the corresponding "con" is related to the

Table I. Route Tunnel Costs in France (Constantin, 1982).

	PERCENT	OF	TOTAL	COST
Cross-Section characteristics	Excavation costs	P.L. costs	S.L. costs	INC. %
- Slightly fractured rock. - P.L. with some bolts and wire mesh. - 30 cm thick S.L.	60%	5%	35%	1,00
- Hard fractured rock. - P.L. with bolts, shotcrete and reinforcing mesh. - 30 cm thick S.L.	55%	15%	30%	1,15
- Mediumm fractured rock. - P.L. with bolts, steel sets, shotcrete and reinforced mesh. - 40 cm thick S.L.	45%	20%	35%	1,55
- Low quality ground. - P.L. with strong steel sets, steel plates and concrete. - 40 cm thick S.L.	35%	45 to 50%	20 to 15%	2,00 to 2,50

Table 2. Cost per running meter of bidirectional route tunnels and equipment cost as percent of total tunnel cost in Europe (Constantin 1990).

COST PER	RUNNING METER ($/m)
LENGTH (Km)	CORRELATION C_n = 0,95098 ; n = 33
1	13,947
1,5	14,586
2	15,056
2,5	15,433
3	15,746
4	16,254
5	16,660
6	16,998
7	17,290

The study is based on data provided by different countries in answer to a quest during 1978-1984. There are data on 134 European Tunnels + 32 American and 9 Japaneese ones.

EQUIPMENT	COST AS PERCENT	OF TOTAL COST
VENTILATION SYSTEM	UNIDIRECTIONAL	BIDIRECTIONAL
NATURAL	7%	9,5%
LONGITUDINAL	9,7%	14%
SEMI-TRANSVERSE OR TRANSVERSE	12%	15%

lg (TOTAL COST IN FF) = 1,11040 lg L (Km) + 1,88923

1FF ~ 0,18 $ (Nov. 91)

impossibility of detecting easily a new water focus.

3.4.1 *Impervious films*

The waterproofing films currently used in tunnels are generally foreseen to be installed between the P.L. and the S.L., being always protected by a concrete layer (for instance 30 cm of a S.L.).

If the S.L. is not built and the same films are used as an apparent finishing the conditions are very different and the study has to take into account the following points:

a) Experience of similar applications to tunnels in service.

b) Fire resistance. It is very important to be sure that, in front of a fire, the film behaves satisfactorily (without forgetting that the combustion gases can be highly toxic).

c) Repairing or substituting a waterproofing film are very complex with the tunnel under service.

d) Aging and Durability of the film when subjected to the typical atmosphere of the tunnel interior. With tests of 1) the "actual" material (if it is a film composed by layers of different properties) 2) "complete set" (film, joints anchorages, etc.).

e) The film setting. Analysing 1) The anchorage systems (it is possible that some "water bags" develop, producing increasing efforts both in the film and in the anchorages). 2) How to avoid the irregularities of the P.L. surface (shotcrete roughness, bolt heads, etc.).

f) Films cleaning (detergent type, chemical attack, etc.).

g) Possibility of Painting (type of paints, etc).

In our experience we have found that the films that are forseen to work between the P.L. and the S.L. do not comply with the conditions needed to have enough safety when they are used as a finishing in route tunnels.

4 CONCLUSIONS

Although the Secondary Lining can be not strictly necessary from the Structural Strength viewpoint its presence is adviceable because: a) It helps to the stability during the whole life of the work, b) Once in service the Control and Repairing are very complex and costly, c) The substitutory works are anyway significative, d) The waterproofing solutions are complex and not absolutely satisfactory, e) The fire safety can be seriously affected, f) The Managing and Maintenance would be much more expensive.

In general, in route tunnels (medium class ground, water seepage, medium to hig traffic intensity etc.) the elimination of the S.L. has to be analysed very carefully being necessary to develop a Cost-Benefit study for every course of alternative actions (to build or not to build the S.L.) including all the economic variables and functional factors and not only the S.L. concrete. Nevertheless having not found a clear solution to the watertightness using a finishing film (specially in relation to the fire resistance) it is recommended that the decision of not building a S.L. be very carefully weighted.

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